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# **DETONABILITY OF NITROUS OXIDE AT ELEVATED INITIAL PRESSURES AND TEMPERATURES**

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## FOREWORD

This technical documentary report was prepared by James A. Laughrey, Loren E. Bollinger and Rudolph Edse of the Department of Aeronautical and Astronautical Engineering of The Ohio State University on Contract Number AF 33(616)-5615, Project 7065, "Aerospace Simulation Techniques Research," Task 7065-01, "Fluid Dynamics Facilities Research." The research on this task was administered under the direction of the Aeronautical Research Laboratories, Office of Aerospace Research, Wright-Patterson Air Force Base, Ohio, with Mr. Robert G. Dunn, Fluid Dynamics Facilities Laboratory, as Project Scientist.

This report covers one phase of the investigation on Contract AF 33(616)-5615.

## ABSTRACT

The detonability of nitrous oxide was investigated at initial temperatures from 23 to 210°C (533 to 870°R) and at initial pressures from 21.4 to 207.1 atmospheres in a high-pressure detonation tube (1.25-inch I.D. by 45 inches in length). No detonations developed during any of the experiments. Some explosions, however, were encountered. The maximum impact pressure was 3.66 times greater than the initial pressure as measured by a quartz crystal transducer. The time intervals of the reactions (from ignition to the maximum pressures) lasted from one to four seconds, which indicated that relatively slow reactions occurred. The results show that nitrous oxide will decompose and burn deflagratively under the conditions employed; at certain higher initial pressures and temperatures, some explosions occurred.

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## SECTION I

### INTRODUCTION

Nitrous oxide ( $N_2O$ ) is of technical interest because it is an endothermic compound and upon complete decomposition its products consist of nitrogen and oxygen. Therefore, this gas holds some possibilities as an energy source for hypersonic wind tunnels since normal air, unless heated to very high temperatures, becomes useless in a tunnel because of liquefaction resulting from cooling during expansion. For hypersonic speeds (Mach numbers  $> 5$ ), it is necessary to heat the air supply for the tunnel or to employ a fluid (e.g., helium or hydrogen) that liquefies at temperatures below that of air. However, it is not possible to duplicate dissociation conditions in the non-air tunnel fluids to simulate those which would be obtained with air that is heated to high stagnation temperature conditions. By employing nitrous oxide in the stagnation chamber, high enthalpy flows can be obtained because of the heat released during decomposition, and the reaction products can be mixed with 0.88 mole of nitrogen per one mole of nitrous oxide to obtain normal dry air. Thus, the airstream passing over an aerodynamic body in hypersonic flight can be duplicated in a tunnel without the use of a combustion system or banks of electrical heaters to supply the high enthalpy gas flow.

In the evaluation of nitrous oxide as a substitute for air in a high Mach number wind tunnel, the question arises as to whether or not nitrous oxide will detonate at specific pressures and temperatures which may be encountered in operation. The detonability of nitrous oxide cannot be predicted theoretically with any degree of accuracy at the present time. Therefore, an experimental investigation was conducted to determine the conditions at which nitrous oxide might detonate. Initial pressures up to 200 atmospheres in combination with initial temperatures up to  $1000^\circ K$  ( $1800^\circ R$ ) were used.

Previous experiments (Refs. 1-17) have shown that the distance which a flame must travel to form a detonation wave in cylindrical tubes depends strongly on the initial pressure and somewhat on the initial temperature for most of the combustible gas mixtures investigated (e.g., hydrogen and oxygen). This distance depends also upon the composition of the explosive mixture and the internal geometry of the vessel. At low pressures nitrous oxide (Ref. 17) could not be detonated by means of exploding wire ignitors although the decomposition flame formed by the ignitor did accelerate as it traversed the length of the tube. In subsequent experiments, higher initial

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temperatures and pressures were employed.

To determine the flame propagation rates during the various stages, ionization probes and electronic counters were used (Refs. 2, 4, 7, 8, 13, 15, 16 and 17). However, the results obtained with nitrous oxide were not satisfactory because the amount of ionization produced in the nitrous oxide decomposition flame was too low to trigger the electronic gates in the chronograph.

Because of these difficulties it was decided to use a pressure transducer at the impact end of the tube to ascertain whether a detonation wave had been established in the nitrous oxide. Thus, the presence of a detonation wave could be established easily since the impact pressure due to the wave would be approximately 25 times as large as the initial gas pressure.

## SECTION II

### DETONABILITY OF NITROUS OXIDE

Appendix I contains a description of the equipment and experimental procedure used in the experiments to determine the detonability of nitrous oxide. The high-pressure detonation tube is illustrated photographically in Figs. 1 and 2. The water-cooled adaptor for the pressure transducer can be seen on the cover plate in Fig. 1. Pertinent experimental data are presented in Table I for all of the experiments that were considered to be reliable.

At first, experiments were conducted with the gas initially at room temperature (23 to 25°C) while the initial pressures ranged from 35.0 to 62.2 atmospheres. The maximum pressure observed at the tube end was only 1.15 to 1.64 times the initial pressure. Figs. 3 and 4 represent typical traces of the output signal obtained from the high-frequency pressure transducer. The final pressures in the tube were obtained with an accurate Bourdon-type pressure gage after the product gases had cooled to the ambient temperature of the tube. Unfortunately, most final pressures listed in Table I are rather inaccurate because of leaks at the connectors caused by the high temperatures and pressures of each reaction. The final temperature and pressure of the gas mixture were recorded approximately 30 seconds after ignition of the mixture. Because of the rather high critical temperature of nitrous oxide, no experiments could be conducted above an initial pressure of 62.2 atmospheres when the gas was initially at room temperature. A more complete discussion of the characteristics of nitrous oxide is given in Appendix I of Ref. 17. Some pertinent physical properties of nitrous oxide are listed in Table II.

To employ higher initial pressures during the experiments, the initial temperature of nitrous oxide was maintained above the critical

temperature by using external electrical heaters wrapped around the detonation tube. It was very tedious to maintain identical initial temperature for a series of experiments due to the length of time required to change the temperature of the large stainless steel tube. Therefore, the initial temperatures varied from 48 to 80°C (578 to 636°R) during these experiments; the initial pressures ranged from 35.0 to 151.0 atmospheres. There was no simple relationship between the observed "impact" pressure and the initial pressure. The term "impact" pressure is used here in the sense that the pressure measurement was made at the impact end of the detonation tube. In general, higher "impact" pressures were obtained with the higher initial pressures. The ratios of the maximum "impact" pressures to the initial pressure varied from 1.3 to 2.13. Although slightly larger than the ratios obtained at the lower initial temperatures, these ratios indicate that no detonation occurred. The final pressures varied between 1.05 to 1.13 times the initial pressure.

During the last experiment in the series described above, three ports on the detonation tube were blown out. As a result the "impact" pressure could reach only a value of approximately 321 atmospheres which was 2.13 times the initial pressure (151 atmospheres). The hot gases eroded the port holes rather badly and the detonation tube required extensive repairs before it could be used again. From the trace obtained on the oscilloscope, it appears that three to four seconds elapsed after ignition before the explosion took place. The trace showed practically a linear relationship between time and pressure increase until the trace exceeded the displacement range and disappeared from the face of the oscilloscope tube. As the previous pressure increases were relative small, the range for the vertical displacement of the trace had been expanded in order to obtain a more accurate indication of the maximum pressure. It is believed that the following sequence of events took place during this experiment. After ignition a decomposition flame formed which burned for approximately three to four seconds. As a result of this decomposition, the unburnt gas was compressed and heated. At some critical pressure-temperature condition, all of the remaining unburned gas exploded at once. This explosion generated the pressure that blew out the ports in the detonation tube. The portions of the tube near the ignitor area were practically undamaged.

Nitrous oxide ignited spontaneously during attempts to fill the heated high-pressure detonation tube to an initial pressure of 21.4 atmospheres; the tube was at a temperature of 325°C (1077°R). During one of the experiments at this temperature, the pressure rise, indicated by the Kistler quartz pressure transducer, was recorded with a Polaroid camera attached to the oscilloscope. This trace showed that the "impact" pressure rose rather slowly during filling operations until it reached a value of approximately 10 atmospheres; at this point during pressurization, auto-ignition occurred and the pressure rose rapidly, in approximately 1/10 second, to a peak pressure of 38 atmospheres and then stabilized at a pressure of about 25 atmospheres.

Because of the spontaneous reaction at temperatures near 1077°R, additional experiments were performed at a somewhat lower initial temperature so that higher initial pressures could be employed.

Another series of experiments was made at initial temperatures between 200 to 210°C (852 to 870°R) and at initial pressures ranging between 21.4 and 89.4 atmospheres. The pressure increases (2.39 to 3.65 times the value of the initial pressure) obtained during these experiments were higher than those measured in the previous experiments which were performed at similar initial pressures but at lower initial temperatures. Also, the corresponding final pressures were higher which indicated that more of the nitrous oxide was decomposing at the higher value of initial temperature. The final pressures were approximately 1.11 to 1.27 times the initial pressure.

Experiments were continued at initial pressures up to approximately 200 atmospheres while the initial temperatures were maintained at approximately the previous values (200-210°C). The highest "impact" pressure obtained in previous experiments was 3.66 times the initial pressure. During the experiment with 113.2 atmospheres initial pressure, the inlet fitting was blown out during the explosion. For an initial pressure of 206.4 atmospheres the maximum "impact" pressure rose to 621 atmospheres or 3.01 times the initial pressure. Again, the tube was damaged slightly when the gas vent port blew out and the supply and vent lines ruptured at the connections. The maximum "impact" pressures obtained during the experiments at initial pressures of 113.2 and 206.4 atmospheres are considered to be fairly reliable. A comparison of the pressure-time histories obtained during these experiments with those measured at lower initial pressures showed that the rapid increases in pressure are similar. For another experiment at an initial pressure of 207.1 atmospheres the maximum "impact" pressure amounted only to 2.13 times the initial pressure. However, the results of this experiment were less reliable because a leak developed around the gas vent port of the detonation tube allowing some gas to escape during the explosion.

During the experiments with initial pressures up to 207.1 atmospheres, considerable difficulty was encountered with leaks at the various ports and at the end plates of the detonation tube. Also the high-temperature gas caused deterioration of the packing in the valves used for venting the tube and frequent replacement was required. Leaks at the ports and the end plates were reduced by modification and frequent replacement of the copper seals used at these locations. The main physical weakness in the detonation tube system occurred in the supply and vent lines which were made from 1/8-inch stainless steel tubing which, in combination with the fittings, could not withstand the extreme pressures and temperatures generated during the experiments at the higher initial pressures. The effect of the high temperatures, attained during the experiments, on the supply and vent lines could be seen afterward; newly replaced lines were blue to black in color close to the tube indicating the effect of extreme heating.

## CONCLUSIONS

From previous theoretical studies (e.g., Refs. 1 and 12) on the properties of detonation waves, it was calculated that the impact pressure of a detonation wave was approximately 25 times the initial pressure depending on the initial conditions and the type of combustible mixture. In the present experiments, which were conducted to determine the detonability of nitrous oxide at elevated initial pressures and temperatures, the maximum "impact" pressure that was obtained never exceeded 3.66 times the initial pressure. This is a much lower value than that expected for a detonation wave. Also, the time interval between ignition of the mixture and occurrence of maximum pressure was relative long (one to four seconds). If a detonation wave had formed during any of the experiments, the maximum "impact" pressures would have been much greater and, probably, the time intervals would have been appreciably shorter.

From the results obtained, it appears that upon ignition some of the nitrous oxide started to decompose thereby raising the pressure and temperature of the unburned mixtures. Undoubtedly some increase in the decomposition flame propagation rate was obtained but not to values corresponding to detonation conditions. During some of the experiments at the higher initial pressures (75.8 atmospheres and above) and at initial temperatures of 200 to 210°C (852 to 870°R), a more rapid reaction occurred as the pressure rise neared its maximum value. This condition could not be interpreted as a detonation, but more likely a moderate explosion of the remaining nitrous oxide gas took place.

From previous studies of the formation of stable detonation waves (Refs. 1-17), the length (induction distance) required to achieve such waves was found to depend upon the type of explosive mixtures, the initial pressure and temperature, the diameter of the tube, the type of ignitor and so forth. The length available in this detonation tube was only 45 inches, which may not have been long enough for a stable detonation wave to be formed. It appears quite possible that a detonation wave in nitrous oxide can be established in a longer tube. However, the present experiments in the short tube gave no indication that the formation of a detonation wave had occurred.

There is the possibility that a detonation wave would have formed at initial temperatures higher than those utilized during these studies; however, in attempting to fill the detonation tube to even a relatively low initial pressure (20 atmospheres), the mixture ignited spontaneously when the wall temperature of the tube was 325°C. This condition prevented use of the detonation tube for experiments at extremely high pressures when the tube temperature was in excess of 200°C.

If nitrous oxide decomposes completely isothermally, the theoretical value of the final pressure would be 1.5 times the initial

pressure. From the results it is apparent that the amount of decomposition increased with higher initial temperatures and pressures, however, complete decomposition was not attained during any of the experiments since the highest final pressure recorded was only 1.27 times the initial pressure.

During a concurrent shock tube study (Ref. 19), the conditions at which nitrous oxide decomposes rapidly were determined. There were some indications that a detonation wave formed in the nitrous oxide during several of these experiments under the conditions of a high temperature and a moderate pressure (approximately 2800°R and 35 atmospheres). Further studies are required to elucidate this effect.

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## APPENDIX I

### EXPERIMENTAL EQUIPMENT AND PROCEDURE

The apparatus used in the detonability experiments is shown in Figs. 1, 2, 5 and 6. It consists of a high-pressure detonation tube with its associated components such as fill and vent tubing, vacuum pump, heaters, ignitor, thermocouple and flow metering and control system. To obtain transient pressure measurements at the impact end of the detonation tube, a Kistler quartz pressure transducer was installed. A 5,000 psi crystal was mounted in a ballistics adaptor so that pressures up to 100,000 psi could be sensed. A transistorized charge amplifier was employed to decouple the high impedance signal; an oscilloscope with a Polaroid camera was used to photograph the traces obtained during these experiments.

The high-pressure detonation tube, Figs. 1, 2 and 6, was fabricated from type 302 stainless steel stock, 5.5 inches in diameter and 45 inches in length. A 1.25-inch diameter hole was bored completely through the center of the stock to form a cylindrical channel. The cover plates and flanges were made from stainless steel also; they were two inches thick and had a diameter of 11 inches. Eight 1 1/2-inch diameter stainless steel bolts held the cover plates in place. A brass ignitor electrode was introduced through one of the cover plates while the center of the other cover plate was drilled and tapped to accept the adaptor for the Kistler pressure transducer. Holes were machined in the side of the detonation tube for the 1/8-inch diameter stainless steel fill and vent lines and their seals. The thermocouple and power leads to an internal heater, which was located inside the channel, were introduced into the side of the tube. The chromel-alumel thermocouple was located at the same end of the tube as the fill tube and the ignitor. A Thermo Electric pyrometer indicator (potentiometer type) was used to measure the output voltage of the thermocouple. The power leads to the internal heater and the vent line were located near the impact end of the detonation tube.

The internal heater consisted of approximately 22 feet of number 18 chromel-A wire wound on a 3/4-inch diameter, thin-walled stainless steel tube 36 inches long. One-eighth-inch long ceramic beads were strung on the wire to prevent it from touching the metal tube. The power input to the heater was controlled by a Variac. During preliminary tests of the internal heater, shorts developed frequently which appeared to be caused by expansion of the chromel-A wire that allowed the ceramic beads to separate and the heater wire to come into contact with either the wall of the detonation tube or the metal heater tube. Due to this difficulty, external resistance heaters were wound on the outside wall of the tube and the internal heater was removed. Insulation, consisting of asbestos tape and Fiberfrax, was wrapped around the detonation tube and heaters to a thickness of approximately 3/8-inch.

Teflon served as pressure seals around the fill-and vent-line plugs, the thermocouple connector and the ignitor electrode during low temperature experiments (ambient to 80°C), and conventional Buna-N O-rings were used to seal the tube at the cover plates. However, for the experiments at higher temperatures all seals, except those around the ignitor, were made from copper because Teflon and Buna-N O-rings could not withstand the high temperatures (200 to 350°C) for any period of time.

A stoichiometric mixture of hydrogen and oxygen at an initial pressure of one atmosphere and at an initial temperature of 40°C was used to check the Kistler quartz pressure transducer dynamically. The experimental value of the impact pressure was compared with the theoretical value which is 464 psia for the above mixture and initial conditions (Ref. 12). An average impact pressure of 434 psia was determined from the oscilloscope traces for six identical experiments. Since the measured value differed by only about six per cent from the theoretical value, the results were considered quite satisfactory. Some difficulties were encountered during the preliminary dynamic calibration of the quartz pressure transducer. The trace on the oscilloscope indicated that signals other than those due to a pressure rise were being transmitted by the transducer. These false signals made it impossible temporarily to determine the magnitude of the impact pressure. By suitable adjustment of the trigger voltage level of the oscilloscope, an acceptable trace was obtained.

The results showed that the Kistler quartz pressure transducer system could be used satisfactorily to determine whether or not a detonation wave had been established in nitrous oxide and in other systems. The pressure transducer was calibrated statically while the crystal was in the ballistics adaptor by pressurizing the detonation tube with air and calibrating the vertical deflection of the trace on the oscilloscope in psi/cm. Measurements showed that the transducer could be calibrated statically and used dynamically because the resulting deflection of oscilloscope traces were equal for this installation. The oscilloscope employed was a Tektronix type 555 Dual-Beam with a Beattie Coleman Polaroid camera attachment. The type 601 Kistler pressure transducer and ballistics adaptor were mounted in a water-cooled housing to maintain the temperature of the quartz crystal at a sufficiently low level to prevent damage and to prevent drifting.

The detonation tube was set up in one of the rocket firing pits, which have 18-inch reinforced concrete walls. Personnel and the auxiliary equipment, such as the oscilloscope, flow controls, pyrometer and so forth were located outside the firing pit; after filling operations were initiated, it was not necessary to enter the pit.

A special exothermic fuze wire called Pyrofuze was used as an ignitor wire. Pyrofuze consists of palladium and aluminum in intimate contact with each other. When this material is heated to the melting point of aluminum (660°C), an exothermic alloying process takes place

which liberates 327 calories/gram so that temperatures in the range of 2200 to 2800°C are obtained. This type of wire was used to produce positive ignition of the nitrous oxide. The Pyrofuze was ignited with a 24 Volt DC power supply.

Prior to conducting an experiment, the heaters on the detonation tube were connected to the power source and the electronic equipment was activated to allow a sufficient warm-up period. Next, a 3/8-inch length of Pyrofuze wire was installed in the ignition circuit and the cover plate was bolted to the flange. Every day, before any experiments were made, the Kistler quartz pressure transducer was calibrated statically by pressurizing the tube with air.

When the temperature of the detonation tube approached the value of the required initial temperature for that particular experiment, the tube was evacuated and then filled with nitrous oxide to a pressure slightly above the initial pressure required. Then the heaters on the tube were turned off and the temperature of the gas was allowed to stabilize for at least ten minutes. This simple method made it difficult to control the gas temperature to within 10°C of the desired initial temperature. However, an exact initial temperature was not needed for the studies. After temperature equilibrium was reached, the excess gas was vented until the required initial pressure was obtained and all valves were closed. Then the gas temperature was measured, the oscilloscope controls were checked and the trace was adjusted to zero vertical deflection which corresponded to the value of the initial pressure in the detonation tube. Thus, any vertical deflection of the trace indicated a pressure rise above the initial pressure. During most of the experiments the trace was free running with one full sweep taking anywhere from one to five seconds since most of the reactions obtained required from 1.5 to four seconds for the pressure at the end of the tube to reach its maximum value after ignition. Then, simultaneously with activation of the ignitor button, the camera shutter was opened and held open until after the peak pressure was reached. The trace on the oscilloscope was monitored manually during the experiments. At the end of the experiment the temperature and pressure values were recorded and the print was removed from the Polaroid camera. Finally the detonation tube was vented and purged with air. After most experiments, the seal on the ignitor end of the detonation tube had to be replaced and a thorough check had to be made for leaks.

## APPENDIX II

### SYSTEM TO OBTAIN HIGH-PRESSURE NITROUS OXIDE

Since initial pressures higher than 75 atmospheres, the maximum pressure in commercial cylinders with nitrous oxide, were needed in the studies of the detonability and flammability limits (Ref. 18) of

nitrous oxide, a special device to increase nitrous oxide pressures up to 200 atmospheres had to be designed and constructed. In this device nitrous oxide was first liquefied and then transferred to a storage vessel that was heated later to a temperature above the critical temperature ( $36^{\circ}\text{C}$ ) of the gas. Pressures in the range from 4000 to 5000 psig were obtained easily by this method. A schematic diagram of the high-pressure system is shown in Fig. 7.

A freon liquefaction system was used to liquefy the nitrous oxide. The gas was transferred from the commercial cylinders to a 10-foot long, seamless stainless steel tube (5 3/4-inch outside diameter by 0.687-inch wall) which contained the freon heat-exchanger coil internally. After the gas was liquefied, it was transferred to a horizontal storage vessel which was contained in a large water tank. The storage vessel was made from a 13-foot long, seamless, stainless steel tube which had a 6-inch outside diameter and a 0.813-inch wall. Nitrous oxide was transferred from the liquefier to the storage tank by having the pressure in the storage tank lower than the pressure in the liquefier. To obtain low values of storage-tank pressure, the heaters in the water bath surrounding the storage vessel were turned off and the temperature of the bath was allowed to decrease to ambient conditions thereby decreasing the gas pressure to the vapor pressure of the nitrous oxide at ambient temperature. Also, the pressure in the liquefier was raised by increasing the wall temperature through the use of heater wire that was wrapped externally on the liquefaction tank.

The valve between the commercial cylinder of nitrous oxide and the liquefier was closed during this transfer of the gas to the storage tank. The liquefaction and transfer processes had to be repeated two to four times in order to obtain enough liquefied nitrous oxide in the storage tank so that the final pressure which could be obtained after heating was in the range from 4000 to 5000 psig. Once sufficient nitrous oxide had been liquefied and transferred to the storage vessel, the valve between the liquefier and the storage vessel was closed and the electric heaters in the water bath were turned on to raise the temperature of the nitrous oxide well above the critical point. All of the stainless steel connecting lines to the flow control stand and to the detonation tube were wrapped with heating wire to keep the temperature above the critical value. This system of obtaining high-pressure nitrous oxide worked satisfactorily and required only minor maintenance work.

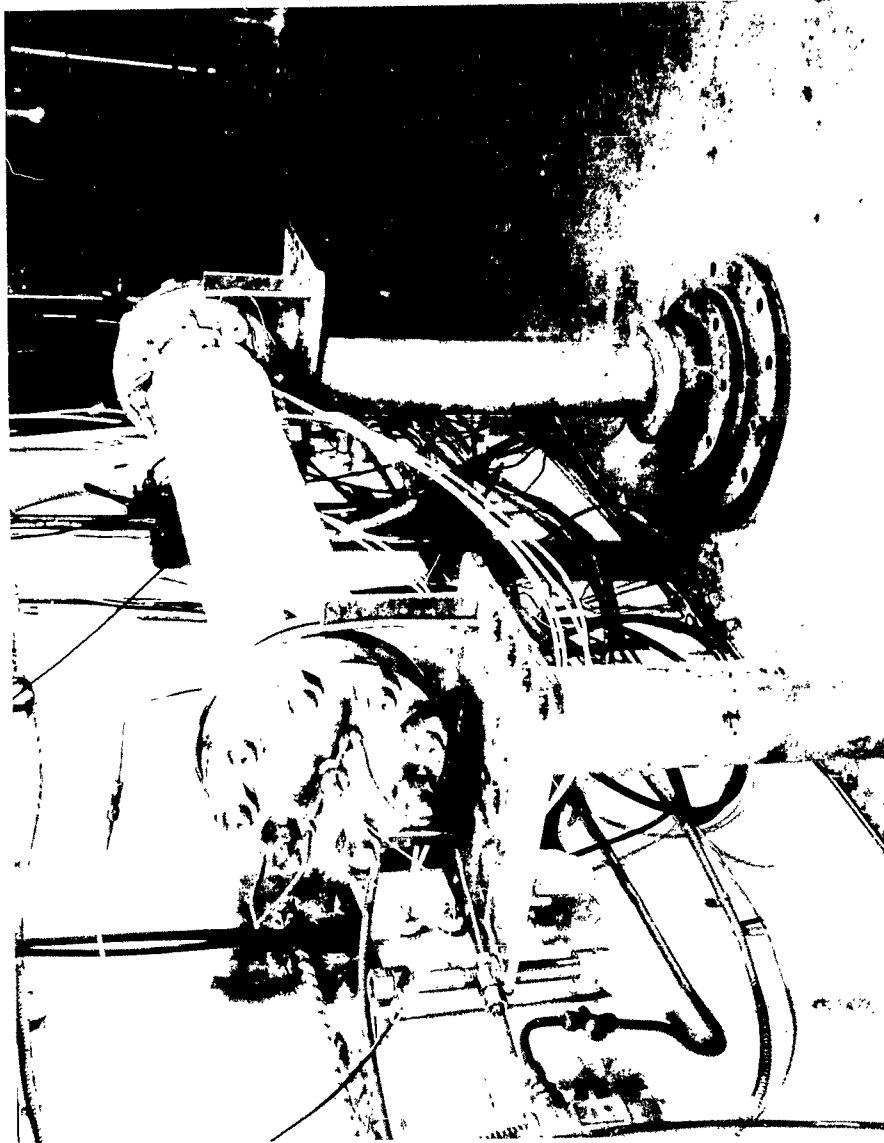


FIG. 1 PHOTOGRAPH OF DETONATION TUBE ILLUSTRATING PRESSURE TRANSDUCER ARRANGEMENT



FIG. 2 PHOTOGRAPH OF DETONATION TUBE ILLUSTRATING IGNITOR ARRANGEMENT

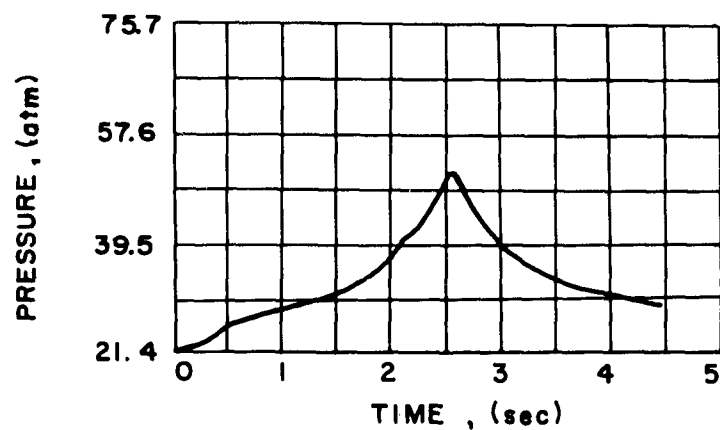


FIG. 3 PRESSURE INCREASE DURING NITROUS OXIDE REACTION; INITIAL PRESSURE = 21.4 ATM , INITIAL TEMPERATURE = 210 °C

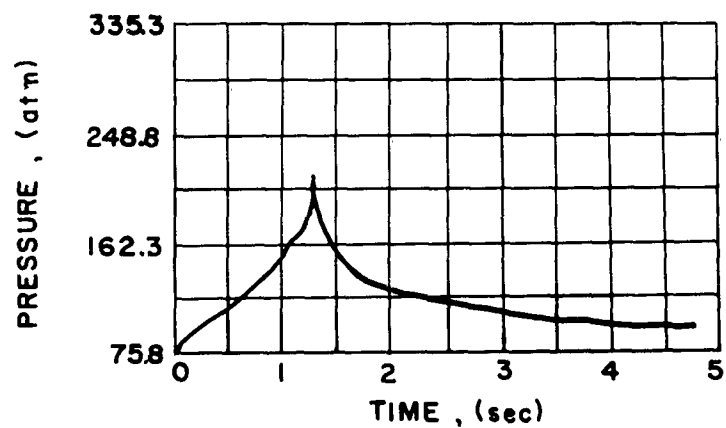


FIG. 4 PRESSURE INCREASE DURING NITROUS OXIDE REACTION; INITIAL PRESSURE = 75.8 ATM , INITIAL TEMPERATURE = 204 °C

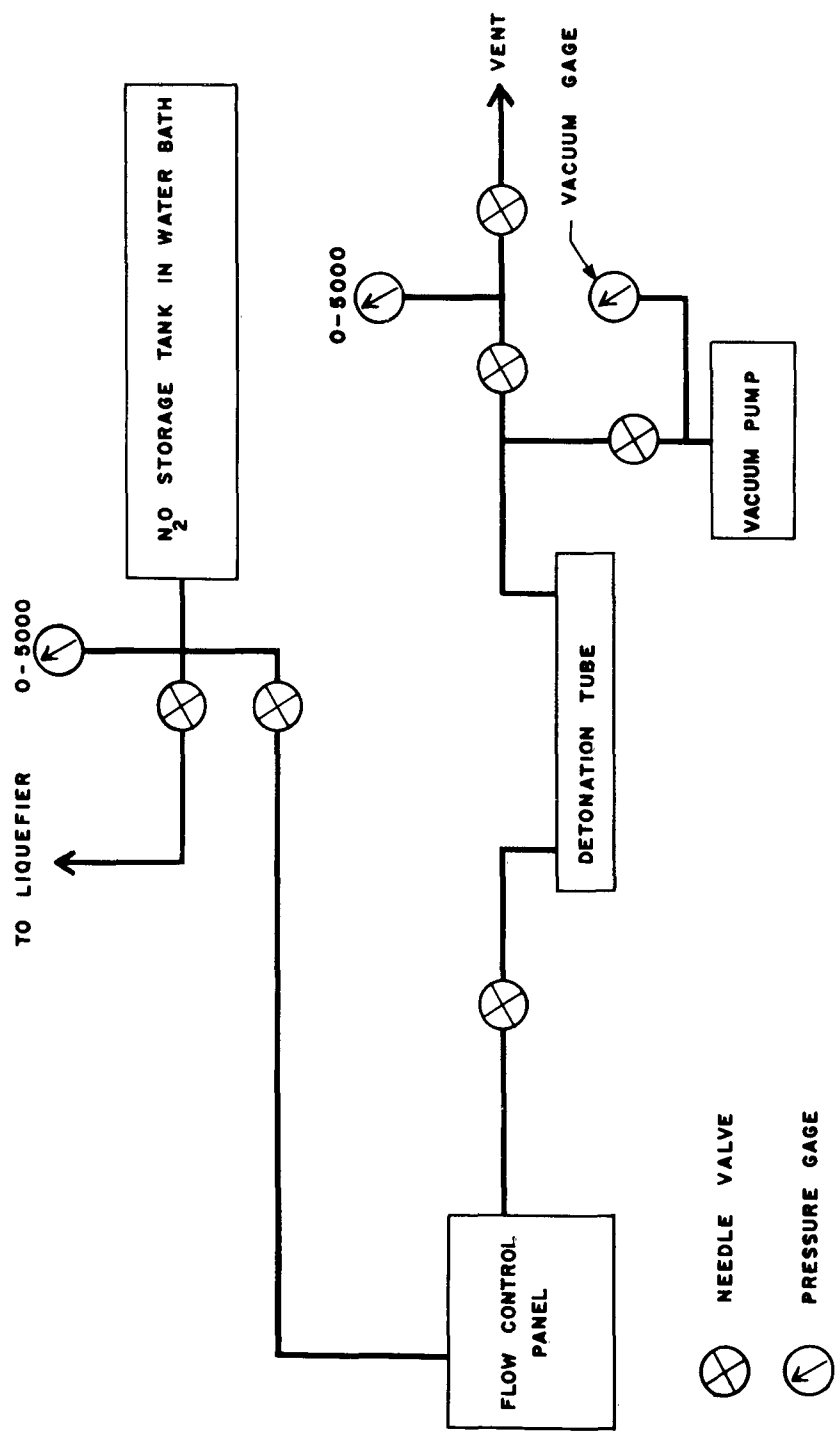


FIG.5 FLOW DIAGRAM OF SYSTEM USED FOR  $N_2O$  DETONABILITY EXPERIMENTS



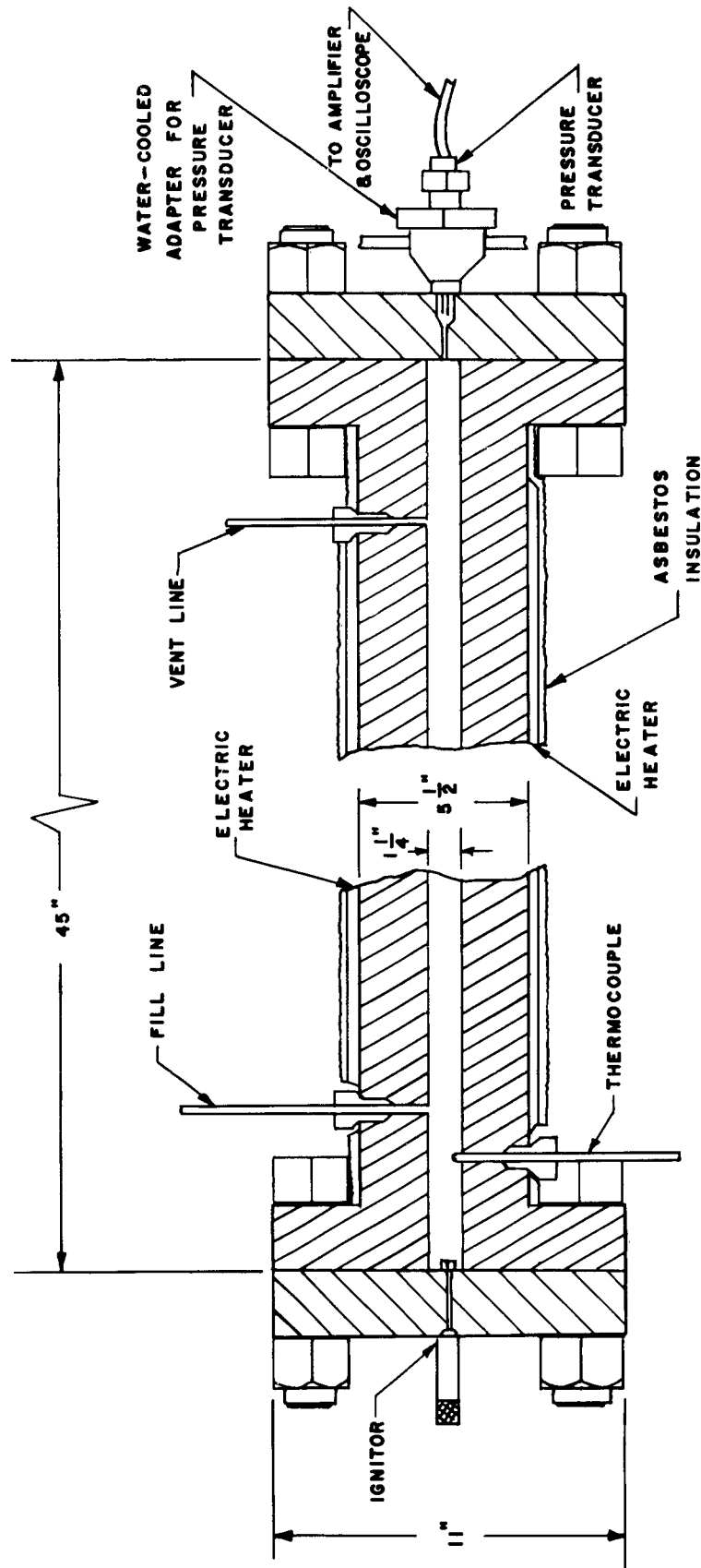


FIG. 6 SCHEMATIC VIEW OF HIGH-PRESSURE DETONATION TUBE

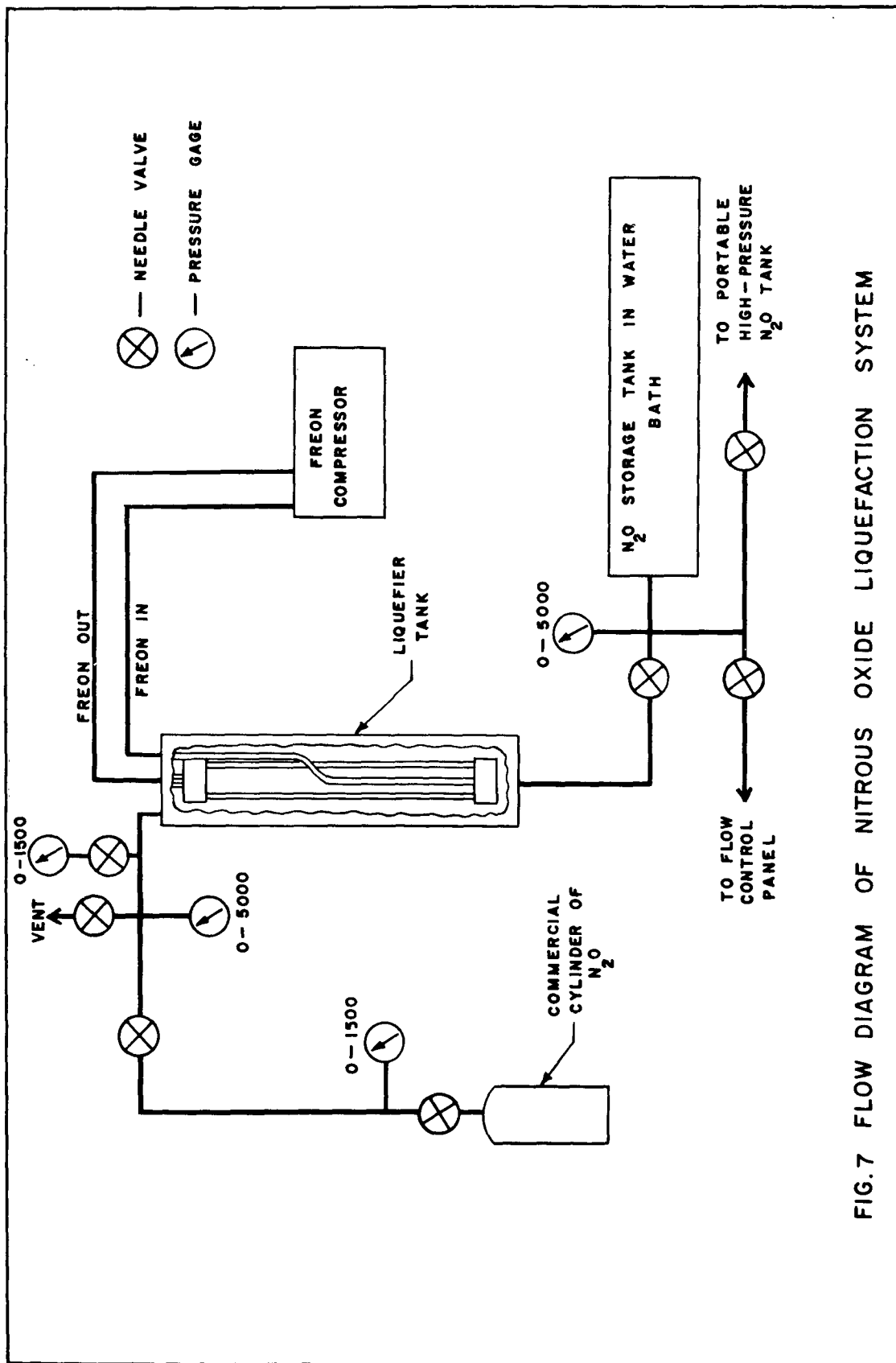


FIG.7 FLOW DIAGRAM OF NITROUS OXIDE LIQUEFACTION SYSTEM

TABLE I  
NITROUS OXIDE DETONABILITY DATA

$T_{\text{initial}}$ (°R)	$p_{\text{initial}}$ (Atm)	$p_{\text{max}}$ (Atm)	$\frac{p_{\text{max}}}{p_{\text{initial}}}$	$p_{\text{final}}$ (Atm)	$\frac{p_{\text{final}}}{p_{\text{initial}}}$
537	35.0	40.8	1.17	ND	ND
537	35.0	40.1	1.15	ND	ND
535	41.8	50.0	1.20	ND	ND
537	48.6	58.0	1.19	ND	ND
537	55.4	65.6	1.18	ND	ND
534	55.4	65.6	1.18	59.9	1.08
537	57.8	73.9	1.28	61.9	1.07
534	62.2	100.0	1.61	ND	ND
534	62.2	101.7	1.64	74.0	1.19
582	35.0	46.1	1.32	39.1	1.12
625	41.8	67.8	1.62	46.6	1.11
616	48.6	68.9	1.42	53.4	1.10
607	55.4	79.5	1.45	60.8	1.10
582	62.2	81.0	1.30	65.6	1.05
580	67.0	90.8	1.36	71.7	1.07
636	82.6	147.9	1.79	93.5	1.13
587	96.2	136.0	1.41	105.7	1.10
582	109.8	177.4	1.62	124.1	1.13
584	123.4	204.2	1.65	139.7	1.13
578	137.0	240.4	1.75	152.0	1.11
614	151.0	321.0	2.13	ND(1)	ND(1)
870	21.4	51.2	2.39	24.8	1.16
852	21.4	54.2	2.53	26.5	1.24
852	35.0	94.4	2.70	43.8	1.25
854	48.6	127.8	2.63	60.8	1.25
888	62.2	161.0	2.59	69.0	1.11
852	62.2	177.2	2.85	70.7	1.14
861	67.0	173.0	2.58	ND(2)	ND(2)
854	67.0	196.6	2.93	79.2	1.18
859	75.8	232.0	3.06	89.4	1.18
863	75.8	236.0	3.11	88.0	1.16
861	75.8	240.0	3.17	89.4	1.18
865	75.8	251.0	3.31	96.2	1.27
857	75.8	267.0	3.52	94.2	1.24
852	75.8	245.4	3.24	92.8	1.22

TABLE I (Continued)

$T_{\text{initial}}$ (°R)	$P_{\text{initial}}$ (Atm)	$P_{\text{max}}$ (Atm)	$\frac{P_{\text{max}}}{P_{\text{initial}}}$	$P_{\text{final}}$ (Atm)	$\frac{P_{\text{final}}}{P_{\text{initial}}}$
852	89.4	326	3.65	ND(3)	ND(3)
861	113.2	415	3.66	ND(4)	ND(4)
870	206.4	621	3.01	ND(5)	ND(5)
870	207.1	441	2.13	ND(6)	ND(6)

ND No data obtained,

- (1) Electrode and gas vent ports were blown out.
- (2) Leak developed in vent valve.
- (3) Gas fill port was blown out.
- (4) Gas fill port was blown out and fill line ruptured.
- (5) Gas vent port was blown out. Also fill and vent lines were ruptured.
- (6) Leak developed at gas vent port during reaction.

TABLE II

## PHYSICAL PROPERTIES OF NITROUS OXIDE

Molecular weight	44.02
Specific gravity (-89°C)	1.226
Specific density (air = 1)	1.53
Melting point	-102.4°C
Boiling point	- 89.5°C
Critical temperature	36.5°C
Critical pressure	71.7 atm
Heat of vaporization at 0°C	59.9 cal/gram
Cubic feet/pound at 21.1°C	8.7

<p>Aeronautical Research Laboratories, Wright-Patterson AFB Ohio. DETONABILITY OF NITROUS OXIDE AT ELEVATED INITIAL PRESSURES AND TEMPERATURES by J. A. Laughrey, L. E. Bollinger, R. Edse. The Ohio State University Rocket Research Lab., Columbus, O. September 1962. 20 p. incl. illus. tables. (Project 7065; Task 7065-01) (Contract AF 33(616)-5615) (ARL 62-432)</p> <p>Unclassified Report</p> <p>The detonability of nitrous oxide was investigated at initial temperatures from 23 to 210°C (533 to 870°R) and at initial pressures from 21.4 to 207.1 atmospheres in a high-pressure detonation tube during any of the experiments. Some explosions, however, were encountered. The maximum impact</p> <p>( over )</p>	<p>UNCLASSIFIED</p>
<p>pressure was 3.66 times greater than the initial pressure as measured by a quartz crystal transducer. The time intervals of the reactions (from ignition to the maximum pressures) lasted from one to four seconds which indicated that relatively slow reactions occurred. The results show that nitrous oxide will decompose and burn deflagratively under the conditions employed; at certain higher initial pressures and temperatures some explosions occurred.</p> <p>( over )</p>	<p>UNCLASSIFIED</p>